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LUTETIAN RAMP CARBONATE FACIES; HIERARCHY AND ENVIRONMENTS, NORTHEAST EL BAHARIYA DEPRESSION, WESTERN DESERT, EGYPT.

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ABSTRACT

With the beginning of Lutetian time, sea drowned the Bahariya paleohigh that had stood as positive blocks subjected to denudation and pedogenesis since Late Cretaceous time. Consequently, a general N to NE gentle sloping ramp developed but with isolated submarine swells and islands. Along this ramp, a succession of fossiliferous carbonate facies (i.e. Naqb and Qazzun formations) onlapped different Cretaceous rock units. The resulting carbonate succession is composed of dolomitic lime mudstones, bioclastic alveolinal/nummulitic wackestones to grainstones, bioturbated skeletal wackestones to mudstones and local ooidal-peloidal packstones to grainstones. These facies assemblages are accreted in three distinct depositional belts, comprising a) back-bank/peritidal belt, b) bank/shoal belt, and c) fore-bank/open marine. The vertical stacking of these facies constitutes shallowing-upward cycles; some of which terminate by paleokarst surfaces with paleosols. Such facies also show a lateral variation in both distribution and thickness that was primarily controlled by the paleogeographic depositional zones within the developed ramp setting, as well as by the pre-Lutetian paleorelief. In the shallow inner ramp zone and around the submarine paleohighs, high-energy nummulitic bank/oolitic shoal facies with peritidal/back-bank dolomitic mudstones predominate. In the middle to outer ramp zones, low-energy skeletal wackestones/mudstones are pervasive with storm-generated nummulitic facies. In local areas, upon the submarine swells (e.g. El Gedida, El Harra and Ghorabi mine areas), the Lutetian carbonate ramp succession entirely changes into a very condensed section of oncolitic-oolitic and nummulitic ironstone facies punctuated by several depositional breaks and unconformities.

INTRODUCTION

The Lutetian carbonate deposits, forming the northeastern plateau of El Bahariya depression (Fig.1), have attracted the attention of many geologists since they are hosting economic iron ore deposits. Most of the previous studies on these carbonates focussed on their lithostratigraphy, structural setting as well as their peculiar karst landforms (e.g. Ball and Beadnell, 1902; Said, 1962, 1990; El Akkad and Issawi, 1963; Said and Issawi, 1964; El Bassyony, 1970; Amer, 1973; El Aref, 1994, El Aref *et.al.* 1987, 1991 & 1999). Little emphasis on the sedimentological aspects and depositional setting had been done, and the general term "shallow marine"or "reefal facies" was assigned for these carbonates (e.g. Said and Issawi, 1964; Saad, 1979, Lotfy, 1988; El Aref, 1994; El Aref *et al.*, 1999 and Abdoul Aal, 2000).

This study aims to analyze the Lutetian carbonate facies of the northeastern plateau of El Bahariya depression, and interpret their depositional environments. The various reported carbonate facies are defined and interpreted based on the facies criteria, i.e. lithological aspect, microfacies associations, depositional textures, fabrics and structures as well as faunal content. The vertical hierarchy of the different recognized facies and the depositional pattern are demonstrated and discussed, guided

with the distinctive parameters and facies sequences of the various carbonate platforms. Four discrete surface sections, representing the compiled Lutetian carbonate succession, are measured, described and sampled (Fig.1, sections No. 1, 2, 4 & 11). The cores and ditch samples from two boreholes (No. 5 & 6, Fig.1) are described for tracing the subsurface extension and thickness of the concerned carbonates. The other surface sections and boreholes (Fig.1) are measured and described to represent the equivalent Lutetian ironstone deposits. The detailed geological setting, ore types and genesis of the Lutetian ironstones and their relationship with the study carbonates appear in the recent publications of El Aref *et al.* (1999) and Helba *et.al.* (2001).

GEOLOGIC SETTING AND LITHOSTRATIGRAPHY

The studied Lutetian carbonate section is a part of the Mediterranean Paleogene sedimentary succession, which is characterized by a flooding of nummulitids and other large foraminifers. Such Middle Eocene nummulitic-rich carbonates were deposited in narrow and elongate tectonic basins representing arms of the Tethys Sea (Salem, 1976). These basins were separated by elongate structural ridges that are inherited from the Upper Cretaceous wrench tectonics. The Bahariya Oases area, particularly its northern sector, stood as positive block since Late Cretaceous time (Said, 1990). With the beginning of Lutetian time, the sea partially drowned this paleohigh, which formed the southern shoulder, margin and the shallow water areas for one of the basins proposed by Salem (1976).

In the northeastern plateau of El Bahariya depression, the Lutetian sedimentary deposits are widely distributed and exhibit distinct lateral changes in both facies and thickness. They are represented mainly by fossiliferous nummulitic carbonates (80-70m thick.) and locally by ironstones (10-15 m thick.). Its succession invariably oversteps different stratigraphic horizons of the Cenomanian Bahariya Formation and underlies either the fossiliferous marl or the glauconitic ironstones and green sands of the Hamra Formation (Late Lutetian- Priabonian). The Lutetian carbonate succession consists essentially of karstified pinkish to yellowish gray limestone, dolostone and marl (Naqb Formaton of Said & Issawi, 1964), grading in the upper part to snow white chalky limestone with characteristic horizons of melon-sized hard silicified limestone concretions (Qazzun Formation of Said & Issawi, op cit.). Most of these rocks are crowded with nummulitids, alveolinids and various megafossils.

The present authors differentiated the Lutetian carbonate succession (Naqb and Qazzun formations) into five distinct stratigraphic units (Fig.2), which can be easily traced allover the study area, and can be correlated with their equivalent units of the ironstone succession (Fig.3).

1- Lower Dolomitic Limestone

This basal unit (A1, Figs. 2 & 3) forms the free face of the northeastern scarp of El Bahariya depression with a thickness varying from 5 to 10 m, due to a local paleorelief of the underlying Cretaceous-Eocene unconformity. Its sole is armored with scattered pebbles and granules of quartz, glauconite and mudstone-clasts as well as ironstone and phosphatic globules being reworked from the underlying Cenomanian clastics. The unit consists of thick to very thick beds of dolomitic limestone and dolostone, which are very poor in megafossils (Pl. 1A). At many

places, the beds are karstified with isolated cavities and fractures that are almost mantled and occupied with crustified and rosette calcite (Pl. 1B). At the mine areas (i.e. El Gedida, El Harra and Ghorabi, Fig. 1), this carbonate unit is reduced in thickness to less than 2 m and changes to red and brown mud-ironstone beds intertonguing with kaolintic mudstone (unit B1, Fig. 3).

2- Lower Nummulitic Limestone

It is a marker unit (A2, Figs. 2 & 3) of the Naqb carbonates succession allover the study area. It ranges in thickness between 4 to 6 m, constituting the summit of the main northeastern scarp of El Bahariya depression. On the plateau, this unit, with the overlying one, forms two or three rows of elongate ridges and step escarpments being nearly parallel to the main scarp. It is characterized by massive and bioturbated bedding, and is crowded with nummulitids, some alveolinids, operculinids and abundant megafossils. The most common fossils are *Nummulites atacicus, N. subramondi, Velates schmiedeli, Cassis nilotica, Gisortia depressa, Lucina subcaillatia and Echinolampas sp.* At the mine areas, this carbonate unit is coeval with a nummulitic-oolitic ironstone unit, which exhibits the same stratigraphic position and yields the same faunal assemblage (B2, Fig. 3).

3- Upper Dolomitic Limestone

This unit (A3, Figs. 2&3) occurs as minor escarpments and isolated buttes on the plateau surface. It is formed of poorly fossiliferous dolomitic limestones and dolostones, (5-10 m, thick), with discontinuous thin bands of limestone breccia, evaporite nodules and terra rosa. At the mine areas, this unit and the overlying unit A4 as well as thick intervals of the Qazzun Formation (unit A5) are obviously missing and expressed by unconformity bounded horizon of thin lateritic mud-ironstone products. These products represent a long time of nondeposition, lateritization and iron enrichment.

4- Middle Nummulitic Limestone And Bioturbated Marl

It constitutes the upper part of the Naqb carbonate succession (unit A4, Figs 2&3), and builds up the numerous karst conehills that litter the plateau surface between El Gedida and Ghorabi mine areas. The unit (20-25 m, thick) is characterized by its grayish, pinkish and reddish tones and by a well bedded nature of intercalating chalky limestone, bioturbated marl and nummulitic/alveolinal beds.

5- Upper Nummulitic Chalky Limestone

It represents the main bulk of the Qazzun Formation (~30 m thick), which is well exposed at the footslope of El Gara El Hamra (Fig. 1). In the district between Ghorabi, El Harra and El Gedida, this unit is almost eroded except few meters forming hard silisified caps on some isolated hills of the Naqb Formation. The unit is distinguished by its snow white colour and occurrence of several horizons of melon-sized silicified limestone concretions. It consists of intercalating chalky limestone and nummulitic beds flooded with large sized *Nummulites cailliaudi, N. variolaria* with molluscan and echinoderms (A5, Fig. 2). At the Eastren Wadi area of El Gedida mine, this thick carbonate unit is correlated with a thin nummulitic ironstone unit (B4, Fig. 3) containing the large-sized *Nummulites cailliaudi* as well as melon-sized, silicified and ferruginized limestone concretions (Helba *et al*, 2001). Such nummulitic ironstone unit is bounded by unconformity, and has a preserved thickness (up to 3m), varying from place to place even in the same mining block.

FACIES AND DEPOSITIONAL ENVIRONMENTS

Six main sedimentary facies, constituting the carbonate succession of the Naqb and Qazzun formations are recognized (Fig.2).

1- Nodular-Bedded Dolomitic Limestone Facies

This facies constitutes the basal stratigraphic unit of the Naqb Formation (Fig. 2). It occurs in the form of thick, to very thick, flat beds (Pl. 1A), which are internally massive, locally faint-laminated and commonly homogenized by irregular and horizontal burrows giving a distinct nodular structure (Pl. 1C). Except for the abundant burrows and a single bank of oysters (10-30 cm thick), the beds are very poor to barren in other mega-fossils.

The facies consists mainly of pale, to egg-yellow, fine-grained dolomitic lime-mudstone, being sandy and glauconitic in the basal beds (Pl. 1D). The essential lime-mud is slightly argillaceous, occasionally with glauconitic and ferruginous clays. It is extensively dolomitized into fine-crystalline dolomite rhombs being commonly with a dark impure core and an outer clear zone (Pl. 1E). In other parts, the micrite is neomorphozed into micro-and pseudo-spars giving xenotopic and hypidiotopic mosaic texture. The oyster bank is dolomitized packstone, consisting entirely of disarticulated oyster valves and fragments. The oysters are completely obliterated with their microstructures and mouldic cavities are replaced or filled with cloudy dolomite (Pl. 1F).

The fine-grain size, matrix-supported fabric, lack of wave- and current reworking features and frequent bioturbation characterizing this facies, indicate its deposition from a suspension in an oxygenated quiet water and below fair-weather wave base. The impoverishment and low-diversity of fauna reflect a restricted water circulation. An abundance of burrows is characteristic, although certainly not diagnostic of restricted subtidal carbonates (Enos, 1983). The distinct nodular bedding of the facies is a common structure of the inner- to middle-shelf or ramp limestone, and is attributed to interplay of burrowing, selective cementation and differential mechanical compaction, particularly in inhomogeneous carbonates (Clari and Martire, 1996). The terrigenous grains of the basal beds are reworked from the underlying Cenomanian clastics during the incursion of the Lutetian sea. In contrast to the essential quiet water lime-mudstone, the grain-supported oyster hash indicates an *in situ* skeletal accumulation with local reworking by sporadic wave or current action. Similar poorly fossiliferous lime mudstone facies is described from both inner shelf- and inner ramp-lagoons behind either oolitic/pelletal shoals or skeletal banks (Enos, 1983; Read, 1985 and Elrick and Read, 1991). The back-bank setting seems to be more appropriate where this dolomitic limestone facies rests directly below skeletal nummulitic banks.

2- Massive To Bioturbated Alveolinal/Nummulitic Limestone Facies

It is the most common and characteristic facies of the Lutetian carbonates succession (Figs. 2 & 3). In the Naqb Formation, particularly in the lower half of the section, this facies truncates the restricted lagoonal and peritidal dolomitic limestone, while in the upper half, and in the Qazzun Formation, it intercalates with the open-marine skeletal wackestone-mudstone facies (Fig. 2). Thick to very thick irregular bedding that swells and pinches laterally is the main bed geometry of this facies (Pl. 2A). Channel-like bedform with concave upward sole as well as megaripples are also observed, particularly where this facies interbeds with the open marine skeletal

limestone (Pl. 2B). Most of the beds are internally massive with chaotically oriented nummulitic tests. However, discrete pockets of densely populated and occasionally imbricated nummulites occur.

The facies is very coarse-grained, moderately sorted and grain-supported bioclastic nummulitic packstone/grainstone (Pl. 2A&C), grading in some layers to wackestone. It is formed of nummulitic tests and fragments with or without few alveolinids and/or operculinids as well as some echinoderm and molluscan particles. Bioclastic alveolinal packstone/grainstone, in which the alveolinids are the pervasive allochem, occurs in few discrete layers in the Naqb formation (Pl. 2D). Intensive bioturbation with branched burrows homogenized some beds of this facies, especially those of wackestone fabrics (Pl. 2E). The bioturbated nummulitic wackestone beds are invariably capped by the grain-supported nummulitic packstone-grainstone facies. In addition to the essential large forams of nummulitids and alveolinids, abundant and diversified megafossils of gastropods, bivalves and echinoderms are recorded. Most of the collected megafossils are robust and of large sizes. In the lower part of the Naqb formation (Fig. 2), the beds of this facies are truncated by paleokarst surface. Its rock in outcrops and from subsurface cores is intensively brecciated and most of the nummulitic tests and other bioclasts are completely dissolved leaving behind oversized intraparticles pores and solution cavities.

The skeletal limestone deposits that contain nummulites in rock forming quantities have been variously recognized as a) reefal facies (Arni, 1965; Philobbos and Kehila, 1991), b) bank, back-bank and shoal facies (Philobbos and Kehila, 1979; Aigner, 1982) and, c) turbidites (Engel, 1970). Aigner (1983 & 1984) gave a comprehensive analysis of the biosratinomical and sedimentological aspects of the nummulitic buildups.

In the study case of nummulitic limestone facies, the abundance and high diversity of fauna indicate an accumulation in open circulated water, under favorable ecological conditions. Nummulites are best developed in well aerated, warm and shallow water on a relatively soft muddy substrate (Blondeau, 1972; Girgis and Hindy, 1973). However, the coarse-grain size and grain-supported fabric of this facies point to a winnowing of a considerable amount of mud and a concentration of the large forams by waves and/or currents. This is supported by the association of large, thick-shelled and robust molluscs, which basically live in a high-energy shoal environments (Enos, 1983). The channel-like and megaripple bedforms as well as the dense population of nummulies in isolated pockets are considered as storm-generated structures (Aigner, 1983&1985; Leckie, 1988; Jennette and Pryor, 1992).

Since, there is neither reef builders nor rigid framework, this nummulitic limestone facies could not be ranked as reefal bodies. Similar Eocene nummulitic facies is considered as "Nummulites tells" accumulated as extensive banks through an *in situ* reworking, winnowing and concentration of nummulites during storm events (Aigner, 1982 & 1983). On the other hand, the heavily bioturbated and matrix-supported nummulitic wackestone rock type of this facies suggests deposition under low-energy and below a significant wave or current actions. The intensive bioturbation probably reflects a low-sedimentation rate (Wright, 1986). This low-energy rock type is commonly capped by high-energy nummulitic grainstones or packstones. It may represent the original nummulitic facies that accumulated under the normal ecological conditions of nummulites, and subsequently reworked *in situ* during storm events to develop the grain-supported nummulitic deposits. According to

Read (1985), the fringing or barrier skeletal bank complexes are of skeletal packstone or wackestone facies, grading up to grainstone caps. They may be burrowed and structureless and may develop on and around paleohighs.

The stratigraphic position of such nummulitic banks, overlying the restricted lagoonal or peritidal mudstone facies (Fig. 2), may suggest deposition during a transgression. The transgressive marine surface may be analogous to ravinements associated with shoreface migration as suggested for the Lower Carboniferous erosively-based bioclastic grainstones (Riding and Wright, 1981 and Wright, 1986).

3- Massive To Laminated Fenestral Dolomitic Limestone Facies

This facies is only recorded in the Naqb Formation (Fig. 2), and represents the second fine-grained dolomitic limestone facies. It attains a thickness ranging between 2 and 4 m, and is encompassed, with erosive contacts, between the nummulitic bank facies.

The facies forms medium to very thick beds (20 - 50 cm, thick for each), that are internally massive, and locally bioturbated (Pl. 2F). These beds often terminate up with thin layers showing faint planar lamination, rippled surfaces and desiccation cracks. Discontinuous thin lenses, with irregular soles, of desiccation breccia, "terra rosa", and nodular gypsum are observed between the main facies beds (Pl. 2F).

The facies is very poor in body fossils but contains some trace fossils. Its rock is pale yellow, fine-grained and mud-supported. It is composed of partially dolomitized lime-mudstone, grading in some beds to dolosiltite. It is characterized by irregular fenestral voids and biogenic mouldic cavities that predominate in the laminated and rippled layers (Pl. 2G). Corroded quartz grains of fine sand to silt sizes as well as few peloids, ghosts of rotten molluscs and micritized algal filaments are occasionally reported. The dolomite rhombs are almost of the ferroan type, inequicrystalline, euhedral to subhedral, mostly zoned and interlocked in mosaic masses. In the laminated layers, the dolomite mosaic is dissected by irregular fractures, partially calcitized and the remnants of dolomite float in a poikilotopic orthospar cement.

This facies, with its characteristic fine-grained, matrix-supported fabric and paucity of fauna, resembles the above described subtidal back-bank (lagoonal) dolomitic limestone facies. However, its gradation to laminated, rippled and fenestral dolomitic limestone/dolosiltite suggests shifting to the intertidal sedimentation and tidal flat progradation. Laminated fenestral mudstone or dolostone is typically formed in intertidal to supratidal zones (Wright, 1986; Elrick and Read, 1991). The recorded desiccation cracks, crackle and collapse breccia, ferruginous regolith, evaporite nodules and dedolomitization denote subaerial exposure and pedogenesis (Esteban and Klappa, 1983). The repeated transition from shallow subtidal to intertidal dolomitic mudstone or dolostone facies, capped occationally by karst breccia/regolith, is currently described as a characteristic cyclic pattern of the peritidal carbonate deposits (Wright, 1986; Goldhammer *et al.*, 1990; Satterley, 1996).

4- Ooidal/Peloidal Limestone Facies

The oolitic limestone facies is uncommon in the study Lutetian carbonate succession. It is locally recorded from the cores of boreholes No. 5 & 6 (Fig. 1), at approximately the lower part of the stratigraphic unit 4 of the Naqb Formation. The facies interval attains about 1.2 m thick, intercalating the open marine skeletal wackestone/mudstone (facies type 5). Since this oolitic facies has been recorded from

the subsurface, its characteristic bedding geometry and depositional structures could not be recognized.

The rock of this facies is moderately to well-sorted grainstone. Its allochems are essentially peloids and altered ooids mixed with few fragmented echinoderm plates and spines (Pl. 3A). The ooids have elliptical shape; their internal microstructure is almost obliterated via micritization and or dolomitization. However, traces of the concentric and radial fabric are occasionally observed. The peloids are of the bahamite type, representing rotten and micritized ooids and some worn echinoderm fragments. The majority of ooids and peloids are outlined by a very thin envelope of isopachous fringes of fine granular calcite representing probably an early marine cementation. In addition to this calcite fringes, isolated patches of fine crystalline dolomite and orthospar occlude some intergranular pore spaces.

The difficulty in recognizing the depositional structures and the intensive obliteration of the ooid fabric hampered the assignment of the depositional environment of this facies. However, its well-sorted and grain-supported fabric reflects an accumulation in shallow agitated water. In modern environments (i.e. Bahamas, Lloyd *et. al,* 1987 and Persian Gulf, Loreau and Purser, 1973), the recent ooid formation is occurring in shoals and beaches in depths less than 5 m. In the ooid shoal facies of both inner shelf (Enos, 1983) and inner ramp (Elrick and Read, 1991) settings, the ooids are almost micritized, dolomitized and mixed with worn bioclasts and peloids. Consequently, the study oolitic facies indicates a period of shoaling in the depositional medium and a progradation of high-energy local oolitic shoal.

5- Massive/Bioturbated Skeletal (Echinoderm) Limestone Facies

This facies is an essential component of the upper stratigraphic unit (unit 4, Fig.2) of the Naqb Formation and in the Qazzun Formation. It currently interbeds with lenses and bands of the nummulitic and alveolinal bank facies, and locally with the ooidal/peloidal shoal facies. The facies forms medium to very thick beds, which are internally massive and faintly laminated or most commonly homogenized by irregular and branched burrows (Pl. 3B). The rocks are very fine-grained, weakly consolidated to soft and powdery in the weathered outcrops. They are of chalky white to grayish white with various colored tints (particularly in the Naqb Formation) comprising pale red, pale pink and yellowish brown due to karstification involving ferrugination.

Petrographically, this facies comprises skeletal echinoderm wackestone (Pl. 3C), whole fossil echinoderm mudstone and lime mudstones. Echinodem plates and spines are the pervasive fossil allochems mixed with few delicate bivalves, other molluscan casts and rare nummulitic tests. In outcrops, the beds of this facies yield abundant dwarfed fossils of various gastropods and pelecypods.

The fine grain size, micrite-supporting fabric and scarcity of wave- and current-generated features indicate deposition from suspension in quiet subtidal water and below the fair-weather wave base. The abundant remains of the stenohaline echinoderms with dwarfed and delicate molluscan fossils reflect open water circulation. The frequent bioturbation or planar laminations with preservation of whole body fossil suggest a rather low rate of sedimentation in a low-energy water condition. These quiet energy depositional criteria with the common interbedding with nummulitic bank facies refers to a deposition in fore-bank/open marine zone.

6- Limestone Breccia And "Terra Rosa" Facies (Paleosol)

This faices is recorded in the lower part of the Naqb Formation. It caps the peritidal- and the nummulitc bank- facies (Fig. 2). The facies has distinct pink, red, and brown colors, and consists of ferruginous nodular and brecciated limestone with solution channel forms and limestone-paraconglomerates, mixed with terra rosa sediments. It varies in thickness from few centimeters up to 0.5m.

The nodular and brecciated limestone represents a highly karstified and rotten limestone rock. However, its internal fabric is modified into a group of closely packed nodules and rubbles that are, in many parts, still fitting to each other's, and preserving the original bedform. The nodules and rubbles have a wide spectrum of grain size and shape and are separated by irregular fractures, that are partially to completely filled with iron-rich clay seams. The limestone conglomerate is poorly sorted and matrix-supported rock, consisting of isolated rubbles of rotten limestone clasts floating in terra rosa clastics (Pl. 3D). In some lenses, the limestone rubbles are completely vanished and the facies is formed entirely of terra rosa. The terra rosa is very poorly sorted, ferruginous and sandy soily materials. Its framework components consist essentially of reworked calcite crystals, quartz and glaucony grains and reworked ironstone and rotten limestone clasts (Pl. 3E&F).. These detritus, which vary from pebble to silt size are embedded in iron- rich micritic mud and amorphous ferruginous clays.

Nodular limestone and terra rosa are the characteristic products of subaerial karstification and pedogenesis of carbonate rocks (Bunting, 1969; Esteban and Klappa, 1983; Goldhammar and Elmore, 1984). The disintegration of the original composition with concentration of iron rich residue reflects the effect of chemical dissolution process. Similar examples of karstified nodular limestone are interpreted as relict *in situ* "C" horizon that originated through a combination of physical, chemical and organic pedogenetic processes with downward infiltration of soily materials (Brewer, 1964; Goldhammar and Elmore, 1984). On the other hand, the limestone conglomerates and terra rosa represent locally reworked soil residuum. This is evident by: a) Matrix-supported fabric with the rotten limestone nodules are discrete, unconnected and enveloped by terra rosa. This fabric argues against an *in situ* origin. 2) The predominance of angular and corroded grains of calcite crystals as well as clasts of colloform and banded geothite and hematite (Pl. 3E-G) indicates a reworking from pre-existing authigenic mineral cements. 3) The presence of exotic detrital grains of quartz and glauconite. The detrital soil residuum appears to be reworked from the unstable upper horizon of the soil profile, either during the karstifiction or via subsequent sea transgression.

FACIES HIERARCHY AND DEPOSITIONAL PATTERN

The above-described Lutetian carbonate facies stack vertically in three types of shallowing-upward cycles. These are a) shallow subtidal cycle, b) peritidal cycle and, c) deep subtidal cycle (Fig.4). The shallow subtidal cycle starts with back bank (lagoonal) dolomitic mudstone or subtidal nummulitic wackestone overlain by storm-influenced nummulitic packstone to grainstone, with or without paleosol cap (Fig.4A & B). The peritidal cycle consists of basal subtidal dolomitic mudstone, which grades upward into intertidal fenestral dolomitic limestone/dolostone (Fig. 4C) and occasionaly terminates by a paleosol. The deep subtidal cycle begins with a subtidal

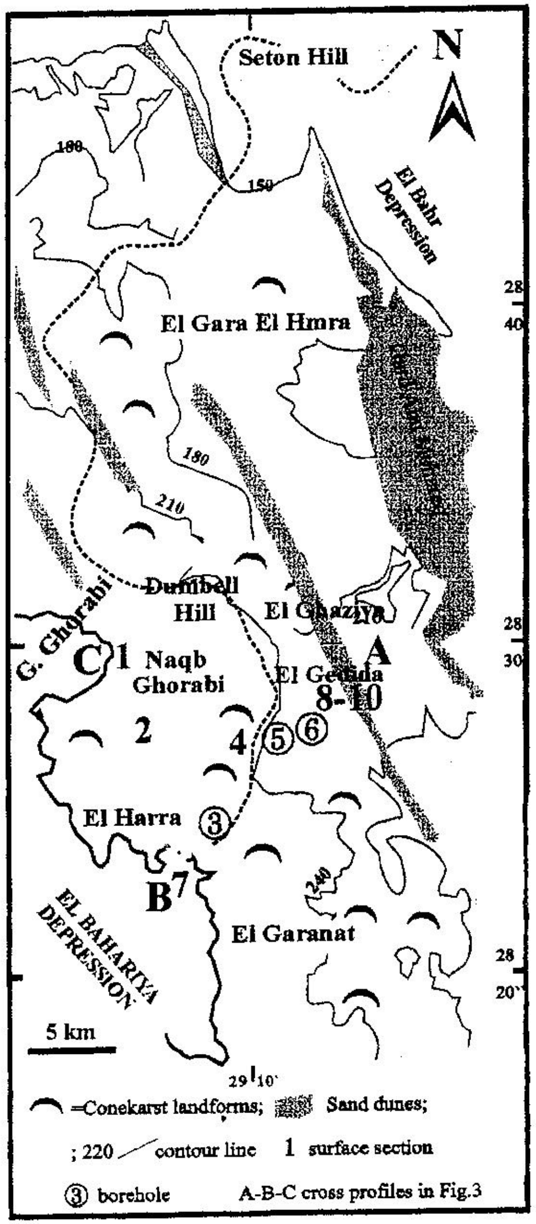
echinoderm wackestone-mudstone, which is overlain by nummulitic or alveolinal bank facies or sometimes by oolitic shoal facies (Fig. 4D).

The accretion of these shoaling-upward cycles resulted from repeated lateral shifting of the three main depositional belts; the skeletal bank/oolitic shoal, the back-bank lagoon/peritidal belt and the fore-bank belt (Fig. 5). The geographic interchange of these belts along the study area can be attributed to sea level changes during Lutetian time span and the local tectonics of El Bahariya region.

The nummulitic banks with other large foraminifers and associated back- and fore-bank facies are common ancient deposits in many parts of the Mediterranean Paleogene (Aigner, 1983). Some of these bank facies are interpreted to have been developed along the shelf platform, particularly from the middle shelf to shelf edge (e.g. Wilson and Jordan, 1983; Philobbos and Keheila, 1991). Other Lutetian nummulitic banks (e.g. Seeb Limestone, north Oman) are described as storm-influenced deposits accumulated on a ramp platform (Racey, 1995). According to Ahr (1973), the carbonate ramps have gentle slopes (generally less than 1°) on which high-energy shallow water facies of the nearshore zone pass gradually downslope (without marked break in slope) into deeper water low-energy deposits. The studied Lutetian carbonates possess the following characteristic features that indicate their deposition on a carbonate ramp platform:

i) The absence of genuine reef deposits and continuous reef tracts. This reflects continuos depositional slope without a major break.
ii) In the upper half of the Lutetian facies succession, the nummulitic bank facies interbeds with the open marine skeletal wackestone/mudstone facies. This reflects the gradual transition from shallow high-energy facies to relatively deep subtidal facies without distinct slope deposits, and thus confirms the lack of a major break in slope.
iii) The shoreward accumulation of the high energy nummulitic bank facies, which is evident by its association with the peritidal- and lagoonal facies and paleosol. This setting contrasts with the shelf sequence where the high-energy and grain-supported facies are more common towards the shelf margin.
iv) The remarkable thickening of the Middle Eocene deposits on going from El Bahariya region towards N and NE, i.e. seawards (Salem, 1976, Fig.1) demonstrates a wedge-shaped geometry for the Middle Eocene accumulations. Such wedging towards the shoreline distinguishes ramp sequences and the reverse is generally true for shelf sequences.
v) The occurrence of storm-generated features, which are common in ramp sedimentation (Tucker, 1985).

The proposed Lutetian ramp was constructed when the Lutetian sea has drowned the Upper Cretaceous Bahariya paleohigh. This ramp was probably sloping towards the N to NE. A series of isolated submarine swells and islands (e.g. El Gedida, El Harra and Ghorabi swells, in the study sector) interrupted the general slope of such a ramp. Along that Lutetian carbonate ramp, the above recognized shallow subtidal and peritidal facies cycles represent the proper carbonate deposits of the inner ramp zone (sensu, Wright, 1986). The facies types of the deep subtidal cycles accumulated along the middle to inner ramp zones (Fig.5). No proper outer to basinal ramp facies (i.e substorm wave base argillite and marl with local mud mounds) are



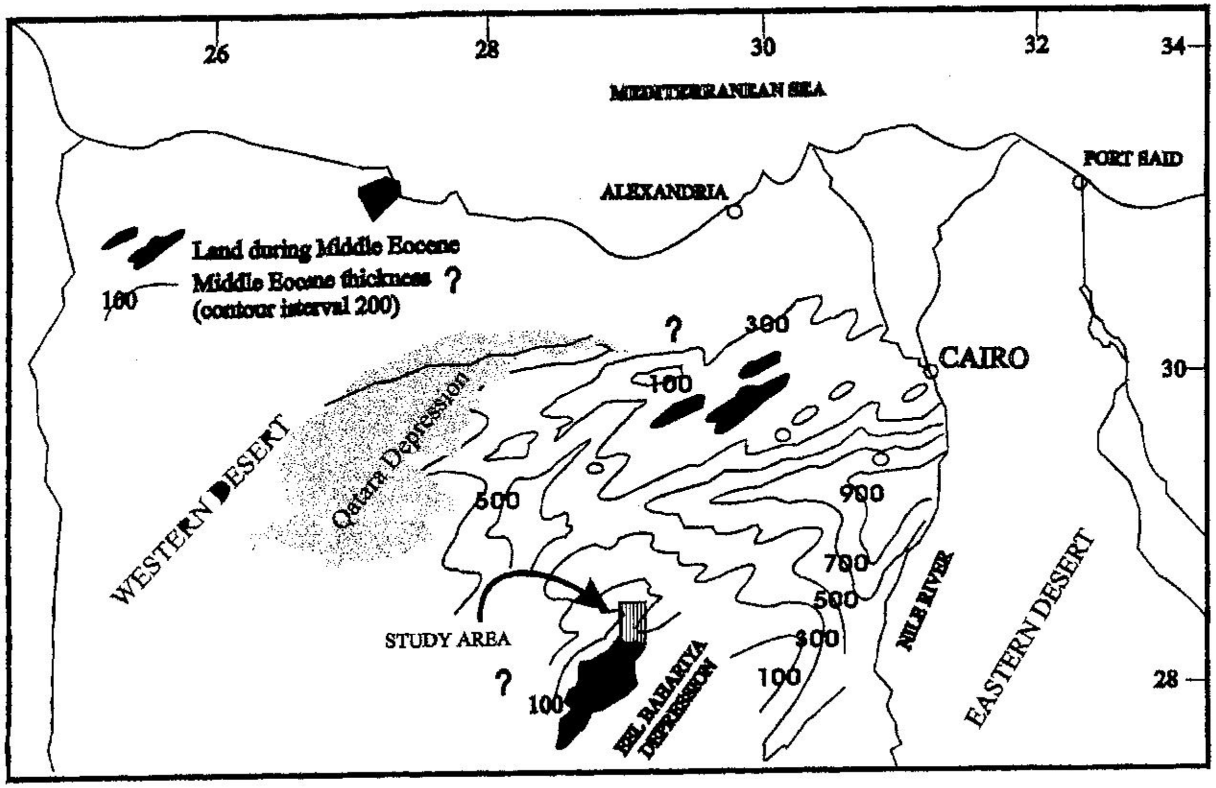
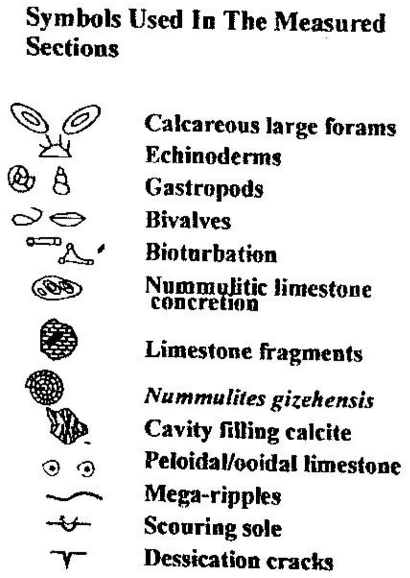


Fig. (1): Location map and isopach contours for the Middle Eocene Deposits in Northeast Western Desret (simplified after Salem, 1976). Note the NE - trending basins separated and shouldered by discrete positive blocks (e.g. El Bahariya block).



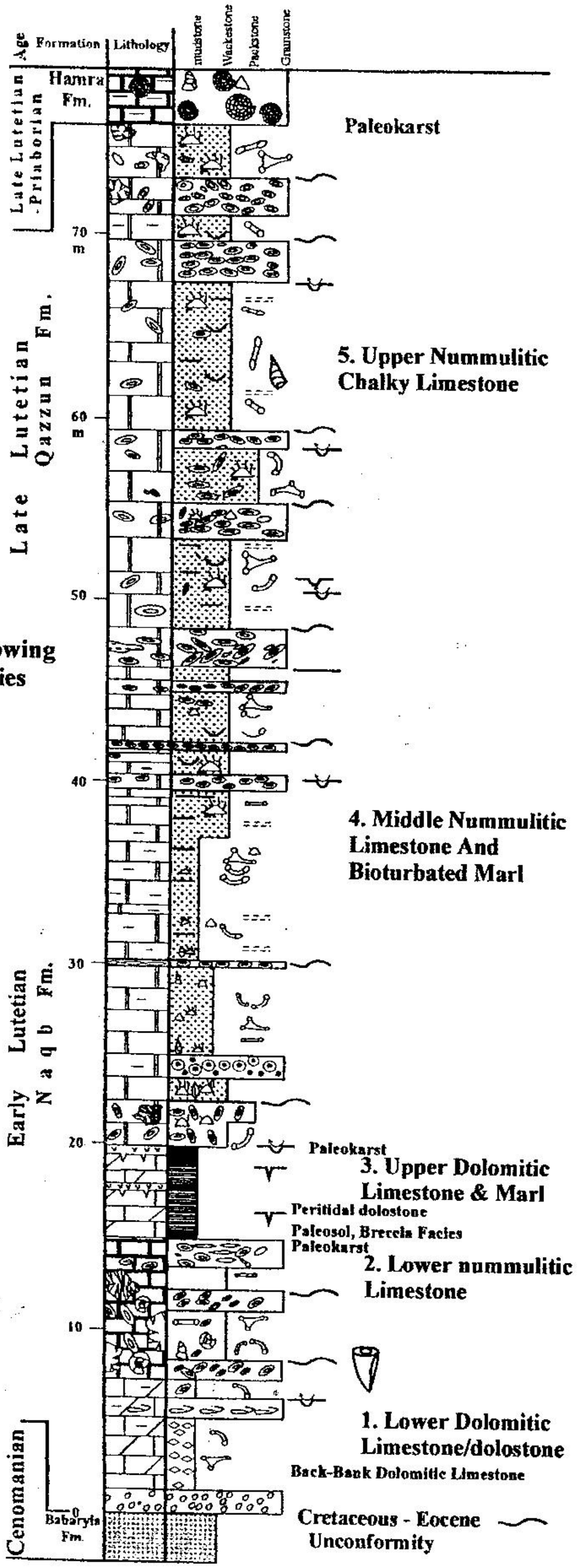


Fig. (2): Compiled stratigraphic section showing the different types of Lutetian carbonate facies and their vertical distribution.

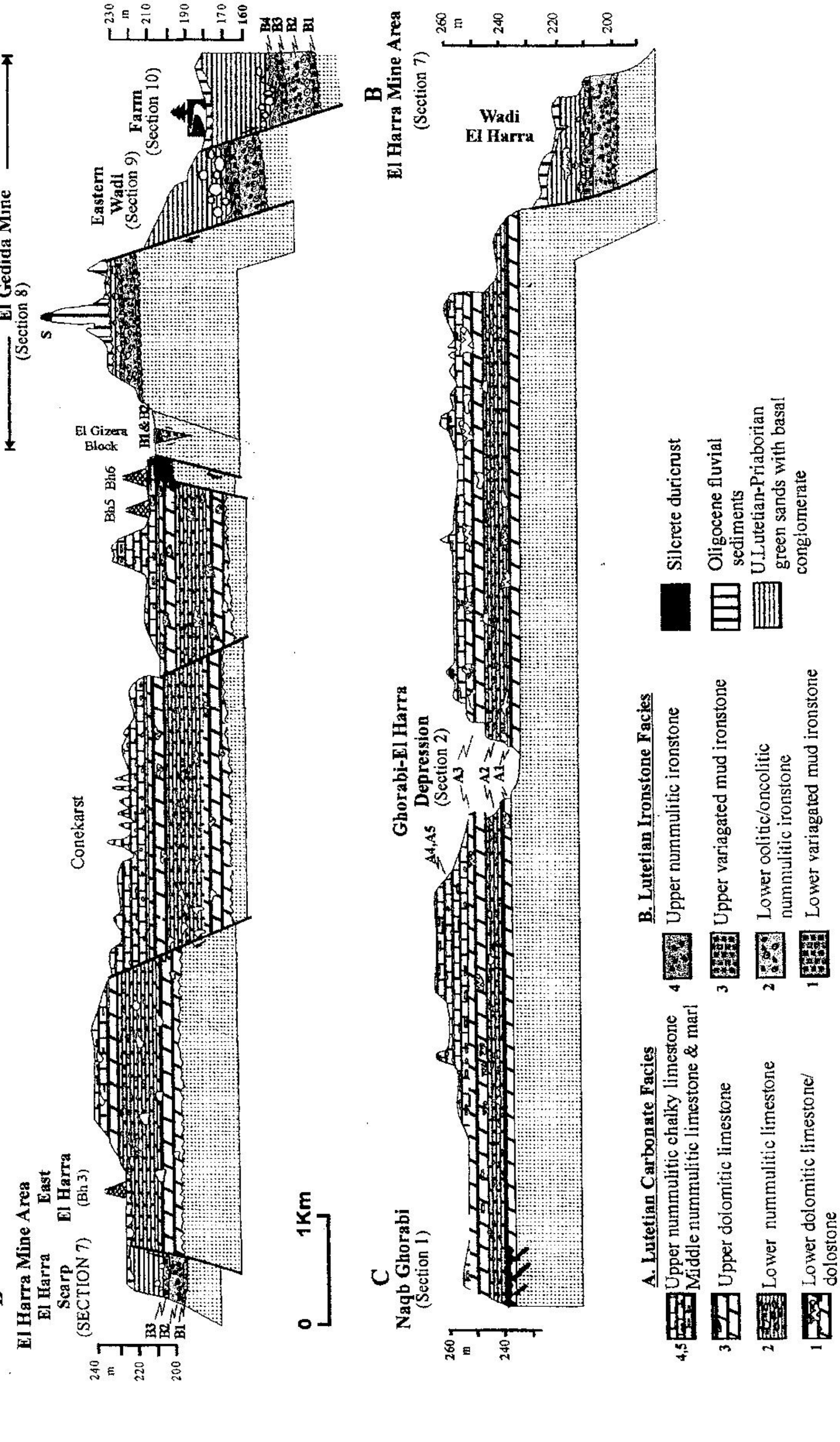


Fig.(3): A-B and B-C cross profiles, showing the distribution of the Lutetian carbonates (facies A1-5) and their lateral change to ironstones (facies B1-4), Northeastern Plateau, El Bahariya Depression

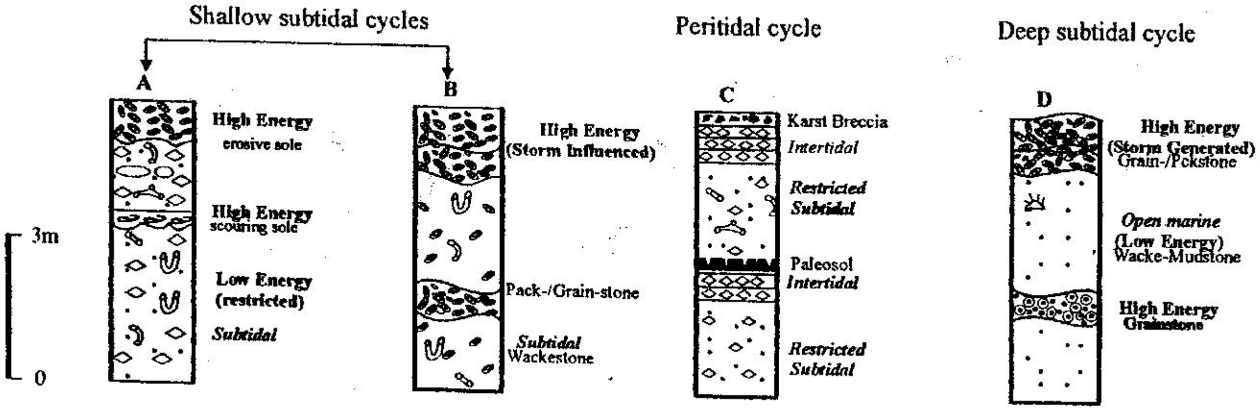


Fig. (4): Different types of shoaling-upward cycles of the study lutetian carbonate facies, (symbols in Fig. 2).

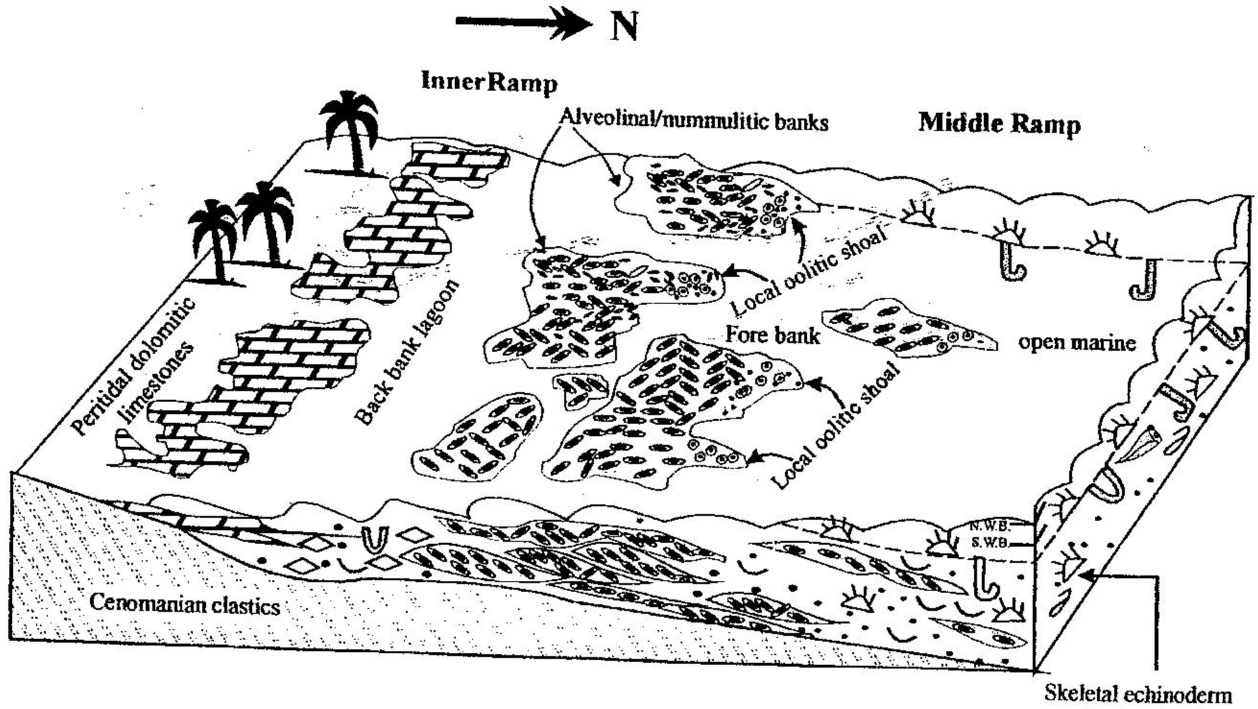
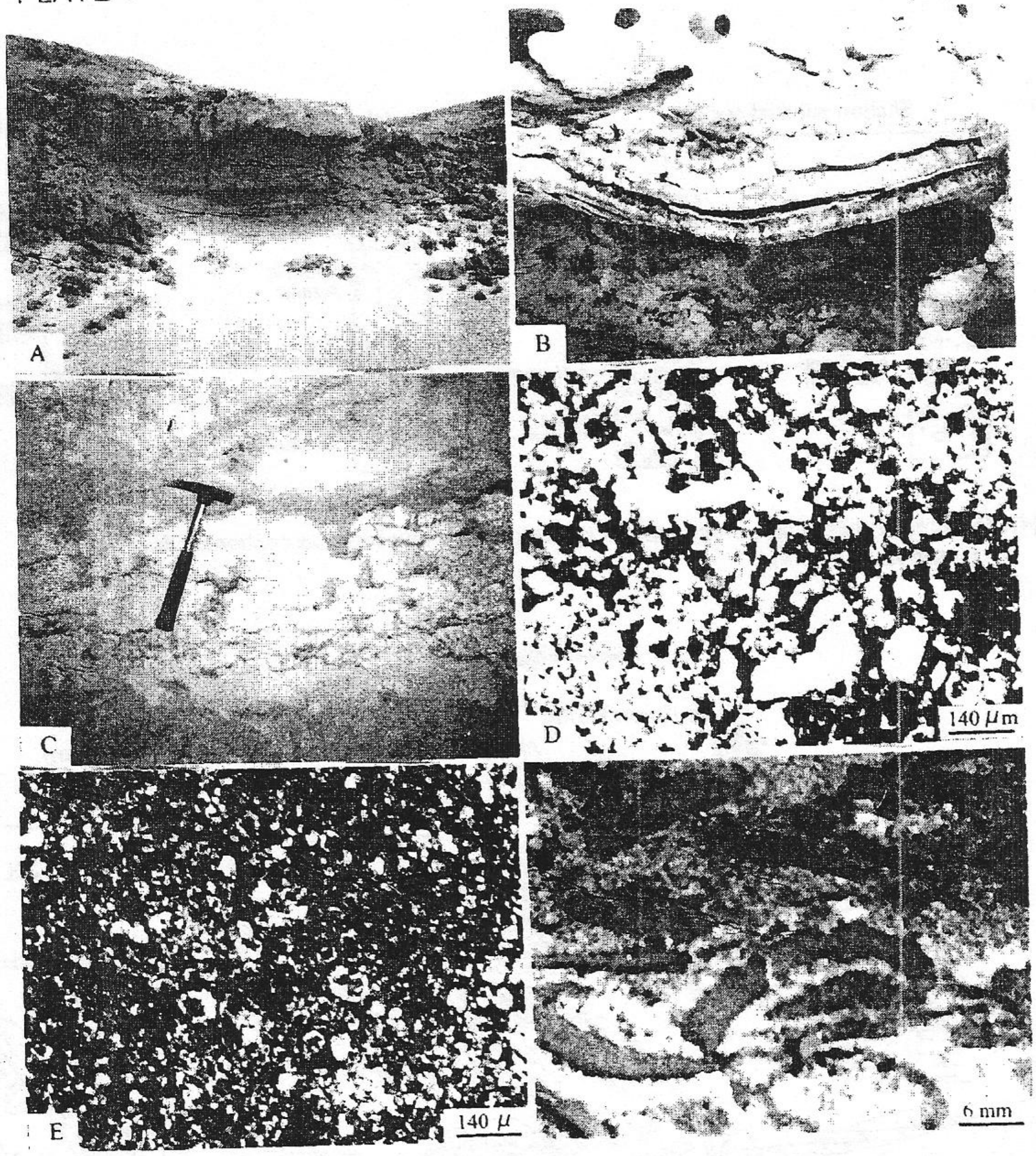


Fig. (5): Schematic diagram showing the different depositional subenvironments of the Lutetian carbonates, N & NE El Bahariya Depression.

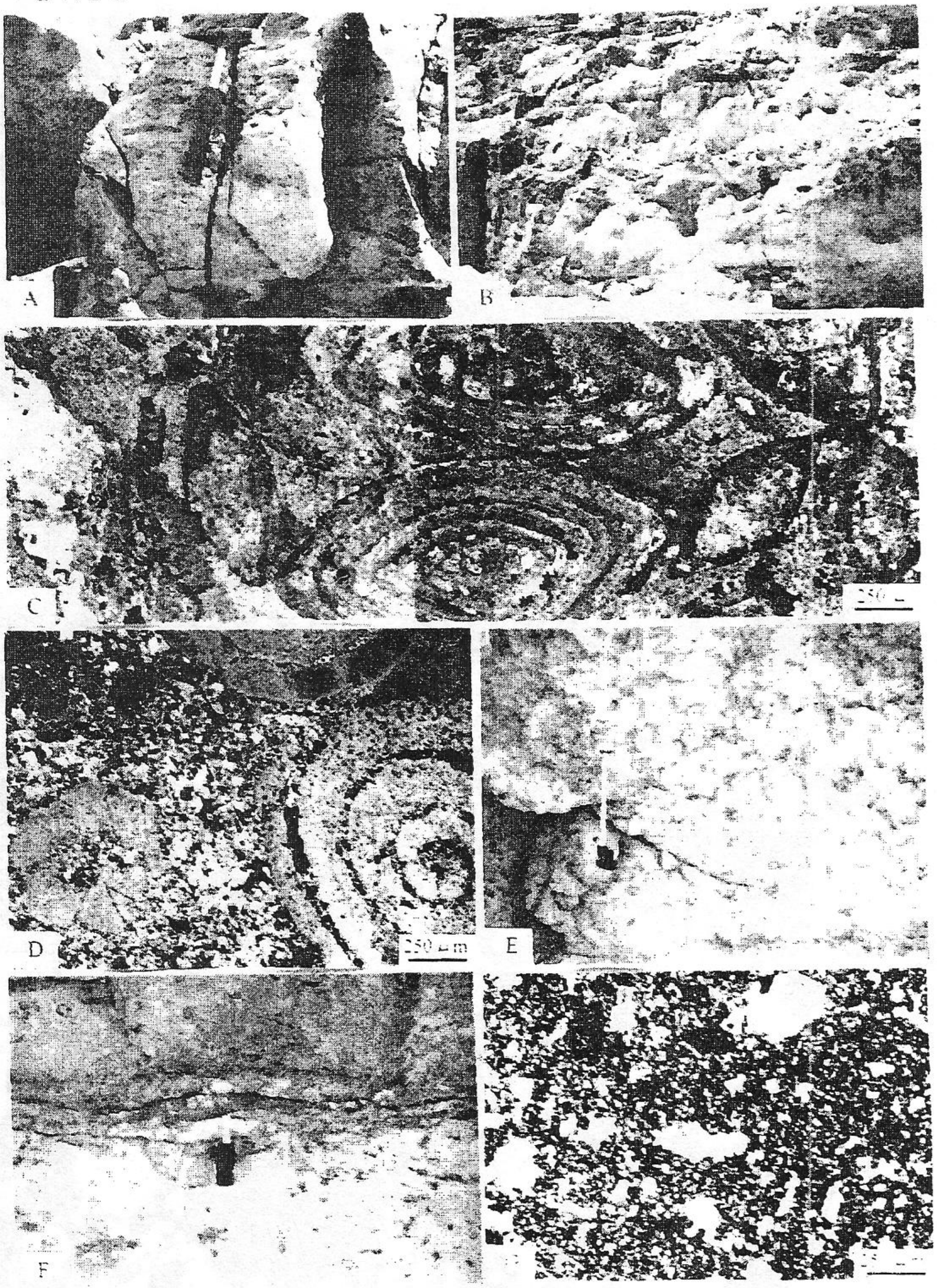
PLATE 1



Pl. 1: A) Thick flat beds of egg yellow dolomitic limestone, showing internal bioturbation and nodular structures. **B)** Fresh water crustified calcite, occluding cavities and fractures that dominate in the karstified lower dolomitic limestone unit. **C)** Distinct nodular structure of the dolomitic limestone facies. **D)** Ferruginous lime-mudstone, being partially recrystallized into microspars and containing scattered quartz and glaucony grains (P.P.L.). **E)** Extensive dolomitization of the lime-mudstone facies into fine- crystalline dolomite rhombs, mostly with a dark impure core and an outer clear zone (P.P.L.). **F)** Oyster shell packstone, consisting entirely of disarticulated oyster valves and fragments set in dolomitized micrite matrix (O.L.).

P.P.L=: Plane Polarized Light. O.L.= Ordinary Light. C.N.= Crossed Nicole

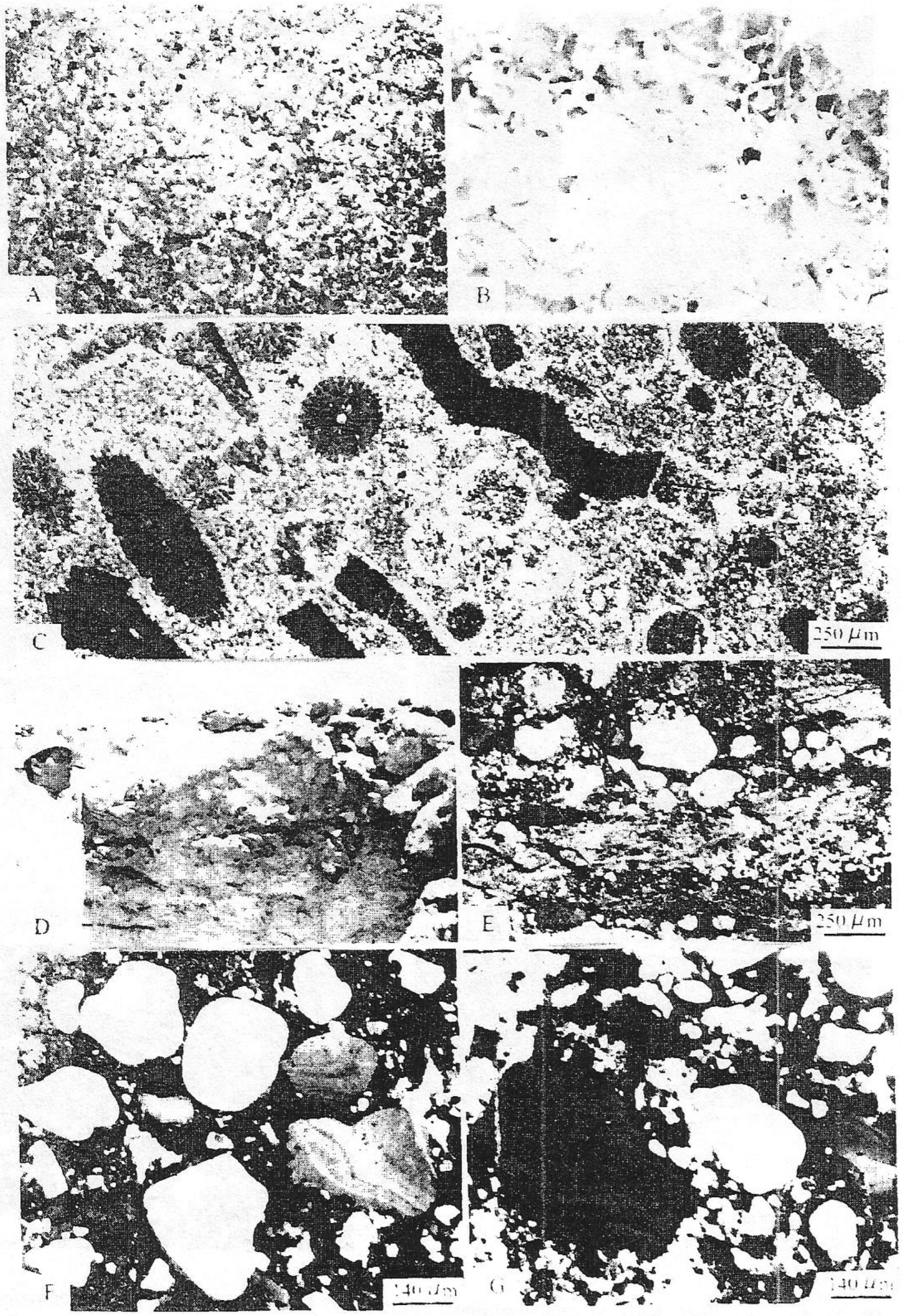
PLATE 2



Pl. 2: A) Very thick beds of coarse-grained nummulitic limestone facies,being rich in chaotically oriented tests and moulds of nummulites and other large forams. **B)** Channel like bedform of nummulitic limestone facies scouring fine-grained chalky limestone beds. **C)** Coarse-grained and grain-supported nummulitic packstone, consisting of nummulitic tests and echinoderm plates set in a micrite matrix (C.N.). **D)** Alveolinal packstone consisting of alveolinid tests embedded in micrite matrix and authigenic quartz (C.N.). **E)** Intensive bioturbation of branched and irregular burrows homogenized some beds of the nummulitic limestone facies. **F)** Thick massive to locally bioturbated beds of fenestral dolomitic limestone facies separated by discontinuous and irregular thin bands of desiccation breccia, terra rosa and nodular gypsum. **G)** Fenestral dolosiltite facies terminating commonly the massive bedded dolomitic limestone (P.P.L.).

P.P.L=: Plane Polarized Light. O.L.= Ordinary Light. C.N.= Crossed Nicole

PLATE 3



Pl. 3: A) Highly porous ooidal-peloidal grainstone, consisting of micritized ooids and bahamite peloids (P.P.L.). **B)** Bioturbated beds of echinodermal limestone facies being heavily penetrated by irregular and branched burrows. **C)** Ecinodermal wackestone facies, consisting entirely of echinodemal plates and spines set in a dense micrite matrix (C.N.). **D)** Poorly sorted and matrix-supported limestone breccia formed of isolated rubbles of rotten limestone floating in a pinkish terra rosa clastics. **E&F)** Poorly sorted terra rosa clastics consisting of rounded quartz and glaucony grains as well as reworked calcite crystals and ironstone clasts embedded in iron rich micrite and clays (C.N.). **G)** Angular clasts of colloform and laminated iron oxides indicating a reworking from pre-existing authigenic ferruginous cement (P.P.L.).

P.P.L=: Plane Polarized Light. O.L.= Ordinary Light. C.N.= Crossed Nicole

recorded in the study sector. In fact, the subsurface concealing of the Lutetian carbonates due N and NE hindered the recognition of the nature of the lateral extension and changes of these carbonates. However, Salem (1976) reported and described subsurface basinal marl and pelagic chalk facies of Middle Eocene age in the north of El Bahariya region. On the other hand, upon the submarine swells of such ramp (e.g. El Gedida, El Harra and Ghorabi mine areas) the carbonate sedimentation rate was probably low and subjected to continuous *in situ* reworking by storm action as well as to several periods of subaerial exposure with pedogenesis and iron concentration. Accordingly, a very condensed section (10-15 m, thick) of Lutetian nummulitic, oolitic and oncolitic ironstones was developed equivalent to the thicker inner and middle ramp carbonate deposits (Helba *et. al.*, 2001).

CONCLUSIONS

During the Early Lutetian time, sea transgressed the exposed Cretaceous Bahariya high, and led to the formation of a carbonate ramp that was sloping due N to NE. The present northern plateau of El Bahariya depression was a part of the inner and middle zones of that ramp. In these zones a thick fossiliferous carbonate succession (Naqb and Qazzun formations) developed and overstepped the Cenomanian Bahariya clastics. In the nearshore inner ramp zone the lower half of the Naqb Formation was accreted. It is formed of back-bank/peritidal dolomitic limestone truncated by storm influenced nummulitic/alveolinal bank facies. The sequence of these facies is punctuated by a number of subaerial exposure surfaces with paleosols.

With the continuous rise and advance of the Lutetian sea, the depositional setting along the study sector shifted towards the middle ramp zone. Consequently, the carbonate sedimentation became dominated by fine-grained skeletal wackestone/mudstone facies with discrete storm-generated nummulitic/alveolinal banks (upper Naqb & Qazzun formations). The proper outer/basinal ramp facies sequences are not recorded in the study area, but they probably occur due N and NE in the subsurface.

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